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The development and application practice of neglected tidal energy in China

Li-qun Liu, Chun-xia Liu*, Zhi-yi Sun, Ru-cheng Han

Department of Electronic and Information, Taiyuan University of Science & Technology, 030024 Taiyuan, Shanxi Province, China

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ABSTRACT

Along the eastcoasts of China are large bodies of water, China has abundant ocean energy resource, such as the theory reserves of tidal resource is about 0.2 billion kW, as early as 1958, Jizhou tidal power station is the first tidal power station in China, which built in Shunde, Guangdong province, and more than 40 small tidal power stations are built in east coastal region in 1960s, and the total installed capacity is about 0.5 MW. But it is a pity, the application and development of tidal energy has not been regarded by the government and ordinary people due to the investment of power plant is big and the technology is not mature, so there are only several small tidal power stations in China, and Jiangxia tidal power station with an installed capacity of 3.2 MW is the most famous. Fortunately, with the rapid development of Chinese economic and society, the renewable and sustainable energy have been regarded by Chinese government, and the application and development of wind energy and solar energy is increasing in an incredible speed, and more and more specialists began to regard the application of tidal energy, and they thought that tidal energy can relieve the energy stress of east coastal region, and many layout of tidal energy exploitation is unfold in recently. This paper discusses the distribution zone and current developmental situation of tidal energy in China. Then, some application practice is described, such as tidal power station and tidal stream turbine. The policies and law of China central government and local governments are described in the following paragraph. At the end, the developmental prospect of tidal energy in future China and the development barriers and recommendations are introduced, respectively.

Contents

1. Introduction

Country industrialization and reform of ordinary people's living standard need more and more electricity power supply, stable power supply is indispensable to every country at present, and electricity power provided the development impetus of country. The economic level and technology state is closely linked with electricity power supply. In a word, not enough energy supply will reduce the industrialization development speed and the improvement of people's living standard. For an actual example, it is well known that China is the largest developing country in the world. With the rapid development of economy, power energy demand in China is rapid increase in all areas of social life, in despite of the annual total installed capacity of electric power is about 0.1 billion kW, but the

* Corresponding author at: College of Electronics Information Engineering, Taiyuan University of Science & Technology, 030024 Taiyuan, Shanxi Province, China. Tel.: +86 351 6111696.

E-mail address: llqd2004@163.com (C.-x. Liu).

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inevitable power cut in summertime electricity peak in many places of China, and the economic loss is big due to power cut, so thousands of enterprise must work at night in order to avoid the daytime electricity peak. Chinese government regards the construction of power plant and power grid, so thousands of power plants located in everywhere in current China in order to ensure the basic electricity power supply. But it should be noticed that most of power energy come from the fossil fuel resource, and the share is about 90% in China, and the coal account for about 70% in recent 30 years, and the inappropriate energy structure will block the sustainable development of country in future. Specially, the fossil fuel resource in South China is scarce, so billions of tons coal is transported from the North provinces of China, i.e. Shanxi, Neimenggu. For example, according to Statistics data, the wastage of coal is more than 2.74 billion tons in 2008, which ranks the first in the world. And the oil wastage is about 0.36 billion tons, which ranks the second in the world. And natural gas wastage is about 80.7 billion m^3 [1]. The total amount of CO_2 emission is about 6 billion tons, which ranks the first or second in the world and the total emission is equal to USA [2,3]. The total amount of SO_2 emission from 2000 is more than 20 million tons, which ranks the first in the world [4]. The zoology is serious polluted due to the large scale exploitation and transportation and application of the fossil fuel resource. China has large number of polluted cities, and the investigation report of World Bank's environmental and economic experts point out that the world's worst air pollution in 20 cities, 10 are in China, such as Taiyuan, Beijing, Urumqi, Lanzhou, Chongqing, Jinan, Shijiazhuang, Qingdao, Guangzhou, and Shenyang. At the same time, the economic loss is more than 100 billion dollars per year due to the air pollution and water pollution [5]. At present, the pollution question not only occurs in big city, but also in small city. And with the large scale exploitation of fossil fuel resource, there are more than 40 resource-exhausted cities in China, such as Fuxin, Daqing, Baiyin, Huaibei and Tongling and so on [6,7]. The flinty status must be immediate improved to achieve sustainable development in future. At present, Chinese central government and local governments have regarded the application and development of the renewable and sustainable resources, such as wind energy, solar energy and ocean energy. For example, the accumulative installed capacity of wind power in China in 2008 is 12,210 MW, which ranks the fourth in the world [8]. According to the news of CCTV, the total installed capacity is about 18,000 MW till June 2009. The output of photovoltaic in 2009 is about 4000 MW, which ranks the first in the world [9,10]. Furthermore, other renewable resources have been used in China, such as bioenergy, ocean energy, and geothermal energy, etc. Certainly, different renewable energy has different development status in China at present [11–25].

At the same time, the rural population accounted for more than 60%, and the total amount is more than 0.8 billions, and with the rapid development of Chinese society, there is more than 0.2 billions rural population work in eastern coastal cities. But the remaining rural population is still more than 600 million, so the energy wastage is big, and the energy structure is more inappropriate than city due to the main fuels in Chinese village are lumber and grass, which induce that thousands of hectares forest are destroyed and billions of tons CO_2 is exhausted and ecological damage of local places are big. In a word, the inappropriate energy structure in Chinese rural area must be rapid improved in order to improve the living standard of rural population.

Fortunately, China has abundant renewable resource, such as solar energy, wind energy and ocean energy, etc. According to the data of Chinese weather bureau (CWB) and literature [20], the total solar energy resources are enormous in large soil area. Certainly, the irradiation is various in different zones. For example, the Tibet and southeast of the Qing-zang altiplano lie in the highest irradiation zone of solar energy, and the annual hours of sunlight is more than 3200, and the annual irradiation amount is about 6600–8500 MJ/m^2. According to the data of Chinese weather bureau (CWB), the total wind energy resources are enormous in large soil area, the total amount of wind energy resources are 3.2 billion kW, and of which can be effectively utilized is more than one billion kilowatt, and offshore wind energy is more than 750 million kW, and the onshore wind energy is about 250 million kW [21–23]. Furthermore, enormous ocean energy exists in Chinese coastal places, such as tidal energy, ocean current energy, wave energy, ocean salinity energy and ocean thermal energy, and more broadly over the ocean energy, including ocean wind energy and solar energy on sea surface, and marine biomass and so on. According to the statistical data, the theoretical installed amount of tidal energy in coastal zone is about 21.79 million kW, and the theoretical electrical energy per year is about 62.4 billion kW h, and the theoretical average power of wave energy is about 12.85 million kW, and the theoretical average power of tidal stream energy is 13.94 million kW, and the total power of ocean thermal energy is about 0.15 billion kW, and the ocean salinity energy is about 0.11 billion kW, and the ocean current energy is about 14 million kW, certainly, the solar energy and wind energy of sea surface are enormous. So China has enormous ocean energy resource, the application and development of ocean energy will take up important place in future energy structure [11–25].

Thousands years ago, human ancestors had already take advantage of tidal energy, such as Tide Mill have been used to grind flour and rice, and Tidal Mill in the world still exists till modern. For example, the tidal power is use to grind millet by Chinese coastal residents, and Chinese Shandong province still preserved the ancient tidal mill at present. Luoyang Bridge located in Quanzhou, which was installed in Luoyang River by the Chinese residents, and the building stone is conveyed by using the tide power before 900 years ago. Certainly, the tidal power has been used in other parts of the world, such as a Tide Mill in England is used to attract visitors, which located in Suffolk County and is established in 12th century. Then the immigrants bring Tide Mill to the Americas in the New World, such as the French set up the first tide mill in the east coast of Canada in the Americas. At present, the application and development of tidal energy have been regarded by governments in the whole world, specially, the developed countries have been establish many actual tidal power stations and tidal stream power projects, such as La Rance tidal power plant in French, which is the largest tidal power plant in the world and have been completed about 40 years, and the installed capacity is 240 MW. Furthermore, many new tidal stream power companies have been developed various generating equipments, such as Pulse Generation Ltd., Lunar Energy Ltd. and SMD Hydrovision Ltd. The technology of United Kingdom is very advanced in tidal stream power region. Tidal energy applications in China have a long history, and some tidal power plants have been established in last century, and China has enormous tidal stream resource at the same time. Furthermore, China's east coast is the most economically developed regions, but the fossil resource is scarce, so billions of tons coal and oil are transported from Chinese Northern provinces. As a conclusion, the tidal energy and tidal stream energy must be regarded by local governments of coastal region. Specially, the tidal energy and tidal stream energy is mainly concentrated in Fujian and Zhejiang province, such as Hangzhou bay is the world-class tidal energy region. With the rapid development of Chinese economy and society, the renewable and sustainable energy have been regarded by central government, so the development of tidal power will be rapid growth in future.

This article will discuss the current situation and outlook of tidal energy applications in China. Firstly, the current energy situation is described. Then, the tidal energy distribution and current development situation are described in following section. Then, actual applications of tidal power station and tidal stream energy in China

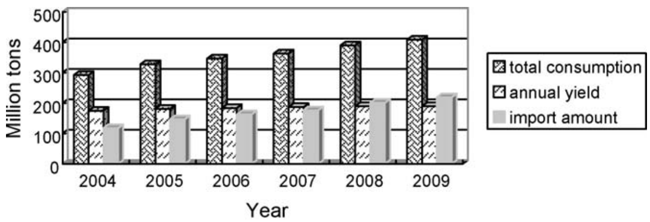


Fig. 1. The total consumption and annual yield and import amount of oil in China [26–32].

are introduced. The following section introduces the technology and policies and barriers. Finally, the prospect of tidal energy in China is forecasted in this paper.

2. Current energy situation in China

The GDP (gross domestic product) of China in 2009 is about 4900 billion dollars, which ranks the third in the whole world, and just behind USA and Japan, and which will exceed Japanese GDP and rank the second in 2010. At the same time, China has a huge population. So the total energy wastage is huge, which ranks the second in the world. According to statistics data, the coal wastage is more than 2.74 billion tons in 2008, which ranks the first in the world, and the oil wastage in 2008 is about 0.36 billion tons, which ranks the second in the world. And natural gas wastage in 2008 is about 80.7 billion m^3 [1]. China became the import country of oil from 1993, and the total domestic production of oil in 2009 is about 0.19 billion tons, which cannot fill the need of country industrialization and development, and the total import amount of oil is about 0.219 billion tons, and the dependence on crude oil imports in 2009 reached about 52.5% [26,27]. As shown in Fig. 1, the annual total consumption is growing form 2004, and the annual domestic yield is stable, and the import amount is rapid increasing. In past 10 years, the annual average growth rate of oil is about 6.6%, which is much higher than the growth rate of the world [33]. For example, the growth rate of Chinese oil consumption in 2006 is 6.7% compare with the growth rate of the world is about 0.7% [34]. And China becomes the biggest oil market [35]. Fig. 2 shows that the rates of external dependence and total consumption growth and annual consumption growth in China from 2004, and the external dependence rate is rapid increasing from 40.4% to 52.5%. Though the total consumption growth rate of oil in recent years in China became slow, but the total consumption amount in 2009 increases about 40% compare with the amount in 2004. The enormous import amount of oil has affected the energy security of country, nevertheless, the oil consumption accounts for about 20% in whole energy structure, and the natural gas consumption accounts for only about 3% in whole energy structure. China has enormous coal resource, so the coal accounts for 70% in whole energy structure in past 30 years. But an important problem is that the coal distribution is very uneven. The enormous region locates in Northern and Western of China, such as Shanxi, Neimenggu, and Xinjiang province. The scarce region locates in Eastern of China, such as Fujian, Zhejiang,

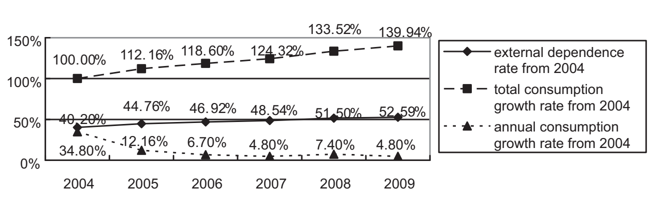


Fig. 2. The rates of external dependence and total consumption growth and annual consumption growth in China from 2004 [26–35].

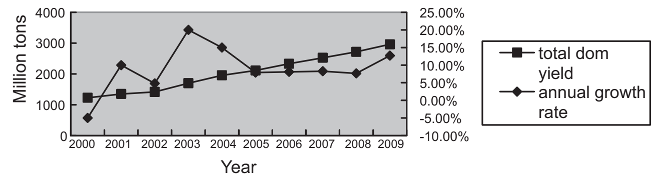


Fig. 3. The total domestic yield and annual growth rate of coal in past 10 years [36–41].

Guangdong, Beijing, and Shanghai, etc. Billions of tons coal is transported from Northern provinces to Eastern coastal region, which increases the transportable pressure of railway, specially, the coal steam-electric plant cannot gain enough coal supply once the storm is coming, and the industrial and residential electricity consumption will be affected by the storm. Certainly, the import amount of coal is small due to the domestic yield is big. But we must regard an important problem, which is that China became an import country of coal from 2009. As shown in Fig. 3, the total domestic output is uninterrupted growth in past 10 years, and the total output in 2009 is about three times in 2000, and the annual growth rate is more than 5%, and the highest growth rate is more than 20%, which take place in 2003. But the import amount will increase in foresee future due to the transportation reason and price reason, and the price of domestic coal is rapid increased, and the coal price per ton is changing form about 60 dollars to 100 dollars. As a conclusion, the energy consumption structure is very inappropriate to the sustainable development. The inappropriate state must be improved, which have brought some environmental damage, such as greenhouse, air pollution, water pollution and soil pollution. For example, the total amount of CO_2 emission in China is about 6 billion tons, which ranks the first or second in the world [2,3]. The total amount of SO_2 emission from 2000 is more than 20 million tons, which ranks the first in the world [4]. A large number of greenhouse gases and pollutants emission have affected the normal living of people and running of society. We have only one Earth, and we have only one homeland, and we love my hometown, so the things must be improved.

Certainly, the severe question has been realized by Chinese central government and local governments and normal people, and Chinese government has established the Renewable Energy Law in February 28, 2005, and the law have acted as the guarantee and special emphasis on the subject of renewable energy development in past 15 years. The People's Republic of China Renewable Energy Law Amendment (Draft) have been discussed and adopted by the 11th National People's Congress Environmental and Resources Protection Committee in July 22, 2009. August 28, 2009, the 11th National People's Congress initial review "The People's Republic of China Renewable Energy Law Amendment (Draft)" at 10th meeting. In a word, Chinese development needs big energy, and the economic and society sustainable development expects the renewable energy. So the development of renewable energy must be regarded by governments and ordinary people in future, or else, the sustainable development is bosh, and the industrialization of China is impossible. At the same time, the ordinary people have realized the essentiality of renewable energy application, and many volunteers joined in the protection of the environment in order to protect their homes and common human Earth. The concerted effort of people and government is certain to improve the inappropriate energy structure.

3. Distribution of tidal energy in China

Tidal phenomenon is a natural phenomenon due to the sun and the moon at different locations on the planet and the Earth's rotation in different gravity generated, and the joint action of the

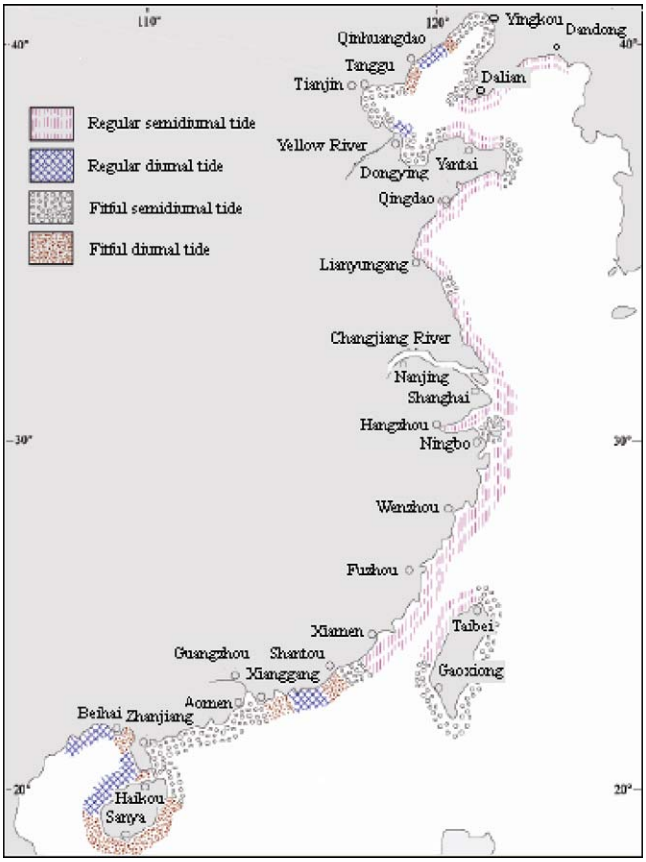


Fig. 4. The tide types distributing in Chinese coastal areas.
Ref. [42].

centrifugal force generated the Earth's tidal force, and the tidal force caused the regular and periodic fluctuation phenomenon of ocean surface, known as the tides. It is well known that China has abundant ocean energy resources in long coastline, and the coastline length is about 18,000 km, and exclusive economic sea area is about 3.5 million km^2, and the island amount is more than 6000, and the coastline length of islands is about 14,000 km. Thousands of years ago, the tidal energy is used to grind the corn and salt by Chinese ancestor and which is used to transport stone and goods. These easy applications are used to improve the life quality of ordinary people until recently, such as Tidal Mill. At present, the modern application of tidal energy is power generation, and tens of small tidal power plants in Chinese east coast have been established from 1950s to 1970s, and the most famous tidal power plant in China is Jiangxia tidal power plant, which is established in 1980, but the total capacity is 3.2 MW. At the same time, China has enormous tidal energy resource in east coast, and the total theoretical reserves is about 0.19 billion kW, and the exploitable amount is more than 20 million kW. So the exploitation of tidal energy resource in China is certain to rapid develop in foresee future [17].

It is well known that the tide include some types, such as regular semidiurnal tide, regular diurnal tide, fitful semidiurnal tide and fitful diurnal tide. These tide types exist in Chinese coastal areas, and different areas have different tide types. As shown in Fig. 4, four tide types distributed from North to South, such as Shanghai, Ningbo, Wenzhou and Fuzhou have abundant tide energy resource, and the best tidal energy located in Fujian and Zhejiang provinces. Table 1 shows the exploitable tidal energy resource of Chinese coastal provinces, and the total area of harbour or estuary is more than 8354 km^{-2}, and the mean range is about 2 m, and the biggest tidal range in China reach 8.93 m, which located in Hangzhou bay. And the total exploitable installed amount is about 21,000 MW, and the total power amount is about 58 billion kW h. Furthermore, some Chinese river estuary occur tidal phenomenon, such as Changjiang, Zhujiang, Yalujiang, etc., so the river estuary area have abundant tidal energy resource, and the theory exploitable reserves of tidal energy in Chinese river estuary is shown in Table 2. Draw a conclusion, China has abundant tidal energy resource in coastal region, and the tidal energy application will replace a lot of fossil fuel resource, and the development prospect is large in foresee future.

4. Application practice of tidal energy in China

4.1. The early application of tidal energy

Chinese people uses the tidal energy since ancient times in order to decrease the labour intensity and improve the standard of living, and they have tried many kinds of method to extract the tidal potential and kinetic energy, such as Tidal Mill, tidal wind turbine and tidal water elevator, etc. For example, Tidal Mill have been used to grind flour and rice, as early as a 1000 years ago, the tidal power is use to grind millet by China's coastal residents, and in currently China's Shandong province still preserved the ancient tidal mill. More than 900 years ago, Luoyang Bridge in Quanzhou was installed in Luoyang River by the local residents, and the tide power is used to convey the building stone. Furthermore, the sea salt is yielded by coastal residents from 1000 years ago, and the seawater of salt field is brought by using tidal variation [1,4].

4.2. The conventional tidal power station

At present, the tidal energy is used to make electricity, and hundreds of tidal power stations are established in the whole world, which have bring abundant economic effects, such as the biggest tidal power station located in France and named La Rance tidal power plant, which is established in 1960s and have been completed about 40 years, the installed capacity is 240 MW, many greater tidal power plants are established and programmed in all over the world. Certainly, many tidal power plants have been established in Chinese coastal provinces from the 1950s, there are 42

Table 1
Exploitable tidal energy resource of Chinese coastal provinces.

Province	Area (km^2)	Mean range (m)	Exploitable installed amount (10 MW)	Annual energy output (MMW h)	Percent (%)
Liaoning	393.4	2.57	58.7	16.1	2.78
Shandong	119.4	2.36	13.98	2.92	0.5
Zhejiang	2584.3	4.29	825	227	39.15
Shanghai	483.0	3.04	70.4	22.8	3.93
Fujian	2859.4	4.20	1033	284	49
Guangdong	1294.5	1.38	69.3	18.37	3.17
Guangxi	645.5	2.46	27	8.07	1.39
Total	8354		2100	580	100

Ref. [17].

Table 2
Theory exploitable reserves of tidal energy resource of Chinese major river estuary.

River	Tidal energy per year (billion kW h/year)	Long dike (km)	Unit energy of long dike (MkW h/km)	The weighted average tidal range (m)
Yalujiang	1.09	5.5	198	2.74
Changjiang	7.8	36	217	2
Qiangtangjiang	59	32.5	1815	5
Minjiang	1.2	5	240	3
Jinjiang	1.5	2.5	600	3
Guangdong	3.3	11.2	295	4
Zhujiang	4.1	25	164	1

Ref. [14].
Note: Data in the table is the original design of planning water office of survey and design department of water resources and electric power Ministry in 1958.

small tidal power plants which located in coastal location, but the installed capacity is very small, and total capacity is about 500 kW, and the equipments of project and electromechanical are simple, and the economic benefit is bad, so the plants were abandoned, Shashan tidal power plant is the last tidal power station. At present, the most of running tidal power station is established in the 1970s, such as the most famous tidal power plant in China is Jiangxia tidal power plant. Table 3 shows the main completed tidal power plant in China. So far, there are eight tidal power stations in China, which are running, and the total installed capacity is more than 6000 kW, and the annual energy output is 10,000 MW h.

As shown in Table 3, the history of application of tidal power in China is long, and the completion time of tidal power plant in China is closing to the completion time of tidal power plant in developed country, but the unit capacity is very small, and the total capacity is small. For example, the Shashan tidal power plant is completed in 1959, and the total installed capacity is only 40 kW, which belong to the construction of large tidal power plant in the 1950s. The Jiangxia tidal power plant is completed in 1980, and the total installed capacity is only 3.2 MW. In a word, the developmental history of conventional tidal power plant in China is early, but the developmental scale is small compare with the developed country, such as France.

4.3. The novel tidal stream power plant

The conventional tidal power station need constructs a big dam in order to store the seawater, the seawater will raise or descend with the changing of tide, so a large soil will be flooded and ecological environment of reservoir will change, such as the dam construction will affect the seawater temperature and sea currents and salinity and the growth of plankton and fish, so it is necessary to study the biological effects of dams. At present, every country and ordinary people regard the environmental protection, the construction of conventional tidal power station is very difficult. In order to apply the tidal power, a novel tidal stream turbine is proposed by some scholar of developed country.

The novel tidal stream power plant is regarded by Chinese government, which is sustained by State Science and Technology Study Projects and Country 863 program, and some university have involved in the tidal stream power program, such as Harbin project university and Zhejiang university. And the original tidal stream power research began in 1983, which located in Jintang island, Zhoushan sea area, and some original designed and test work have been developed, such as power generation test, model experiment and the design of Carrier and anchor block and chain and float barrels and turbine. At present, the first tidal stream power plant in Asia is completed in 2005, the total installed capacity is about 40 kW, and the total investment is about 250,000 dollars. A new tidal stream power plant will be built in this sea area in future, and the total installed capacity is about 120–150 kW [43,44].

5. Tidal energy exploitation technologies

5.1. The exploitation technologies of conventional tidal power plant

The potential energy of tide is used by the conventional tidal power plant, which generally includes three parts: dam, sluices, and power plants. The tidal flow direction is constantly changing due to the tidewater at the fluctuation, and the tidal power plant have different types, such as one-way and single reservoir tidal power plant which can make electricity at ebb tide, and bi-directional and single reservoir tidal power plant which can make electricity at ebb tide and flood tide, and dual-reservoir and one-way tidal power plant which can continuous make electricity. The world's first small tidal power station was built in 1912, which located in Husum Germany. And the world's first tidal power plant is La Rance tidal power station in 1966, Brittany, the west coast of France, which has the big economic value, and it uses bi-directional and single reservoir type, and the total installed capacity is 240 MW, and the annual generating capacity is 544 million degrees [45].

The configuration of conventional tidal power plant includes three types, which names as one-way and single reservoir, bi-directional and single reservoir and dual-reservoirs and one-way. (i) One-way and single reservoir tidal power plant can make electricity at ebb tide by using the water turbine set, and the tide is used to make electricity in only one direction. So the efficiency of this type is low; (ii) bi-directional and single reservoir tidal power station need to build a dam and hydroelectric generating set can make electricity at the flood tide and ebb tide by using the water turbine engines, generating sets is stopped only in the inside water level of

Table 3
The completed tidal power plant in China.

Name	Location	Installed amount (kW)	Annual energy output (MW h)	Begin and completion time
Jiangxia	Wenlin, Zhejiang	3200	10,000	1974–1985
Liuhe	Taichang, Jiangshu	150	150	1973–1976
Shashan	Wenlin, Zhejiang	40	93	1958–1964
Yuepu	Xiangshan, Zhejiang	300	160	1970–1972
Xingfuyang	Pingtan, Fujian	1280	3152	–1990
Baishakou	Rushan, Shandong	960	1000	1971–1978
Ganzhutan	Shunde, Guangdong	5000	10,300	1971–1974

Refs. [14,17,18].

reservoir is almost equal to the outside water level of reservoir. So the efficiency of this type is higher than the efficiency of one-wan and single reservoir tidal power plant; (iii) the dual-reservoirs and one-way tidal power station need build two adjoining reservoirs, namely, high-water reservoir and low-water reservoir. The high-water reservoir has a water intake sluice, when the water level of high water level is lower than seawater level, and the tide water flow to the reservoir. The low-water reservoir has a water release gate, and the seawater flows from low-water reservoir to sea only when the water level of low-water reservoir is higher than the water level of sea. So it can continuous make electricity, and the output efficiency is higher than the output efficiency of one-way and single reservoir type and bi-directional and single reservoir type. Certainly, the investment is big.

Water turbine power set can transform the tidal energy into electrical energy, which is the important equipment of tidal power plant. It include hydro-generating unit, power transmission and distribution equipment, lifting equipment, control room and lower water flow channels, etc. The hydro-generating unit has a good characteristic of low head and large tidal flow, certainly, which must has a good characteristic of anti-corrosion and moisture and anti-fouling properties and insulation and sealing properties. Hydro-generating unit are generally three types of basic structures: (i) vertical axis generator unit, that is, vertical axis turbine and generator connected perpendicular to the water surface. The type require biggish workshop and bigger investment, while intake pipes and tail pipes is very curving, biggish water energy losses, low efficiency; (ii) horizontal-axis unit is turbine and generator shaft parallel to the water surface, the curvature of intake pipes and tail pipes is less than the curvature of vertical axis generator unit, reduce in water energy losses, efficiency increase, but which need the relatively long workshop; (iii) through flow turbine (straight-flow turbine), which include two types, named bulb-type units and rim-generator turbine. Bulb-type units set all equipments in a concrete sealed bulb body, and the equipments include turbine, gearbox and generator sets, and the entire bulb body placed in water flow channels. The merit is that the efficiency is relative high, the curvature of water flow channel is small, and the water energy losses are small. The drawback is that installation is inconvenient, taking up more water channels. An actual example, the La Rance tidal power plant in French uses this type. The rim-generator turbine install the stator of generator in the internal wall of water flow channel around the turbine, and generator rotor is installed in the water flow channel in a sealed body, taking up water channel is smaller than the through flow turbine structure. An actual example, Annapolis tidal power plant in Canada uses this type, unit capacity of 20 MW [14,45].

5.2. The exploitation technologies of novel tidal power plant

The surrounding environment of the traditional tidal power plant will be impacted by the dam construction, and the dam will impacts the ocean currents and water temperature and salinity, which need the huge amount of investment, so the potential energy application of tidal energy is limited in future. At the same time, the tide has abundant kinetic energy, and the kinetic energy application of tidal energy has become a development hotspot at present, that is the tidal stream energy is converted into electrical energy. Tidal stream power generation devices uses the tidal flow, which is fixed at the sea bed, and which is below the sea surface, certainly, which does not impact the shipping and sea currents and water temperature and salinity of surrounding region, which does not need to flood the land, and the impact on people and fish is small, which will not hurt the fish due to the rotation speed of water turbine blade is slow.



Fig. 5. Gorlov helical turbine.

Ref. [46].

The principle of tidal stream power generator is similar with the principle of wind power generator, which looks like an inverted wind driven generator. The different part is the density and speed and direction of wind and tide, so the blade configuration is different. According to the data, the density of seawater is about 832 times of the air density, and tidal stream speed is lower than the wind speed, so the blade of tidal stream power generation is short and crude compare with the blades of wind power turbine is long and thin. Generally, the direction of wind is unstable and continued changing with the changing of weather, so the blade control of wind power turbine is difficult, and the wind turbine must be stopped if the wind speed is greater than the rated wind speed. The direction of tidal stream is relative stably, in generally, which need take into account two tidal stream direction, flood tide and ebb tide. So the blade control of tidal stream power turbine is easier than the wind turbine blade control.

Certainly, the structure of tidal stream power turbine includes two types power turbine, which are the horizontal axis and vertical axis tidal turbine, which is similar with the structure of wind power turbine. The vertical axis tidal stream power turbines are shown in Figs. 5 and 6, the rotation axis direction of tidal turbine blade is perpendicular to the seawater flow direction, such as the Gorlov helical turbine and Tidal Fence Davis Hydro Turbine. The horizontal axis tidal stream power turbine is shown in Figs. 7 and 8, and the rota-



Fig. 6. Tidal Fence Davis Hydro Turbine.

Ref. [47].



Fig. 7. Tidal Stream Turbine (TidEl).
Ref. [48].

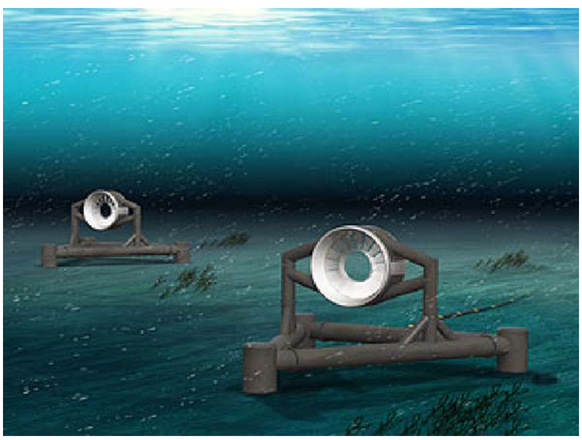


Fig. 8. Open centre turbine.
Ref. [49].

tion axis direction of tidal turbine blade is parallel to the direction of seawater flow, such as the TidE1 tidal stream device and Open centre turbine. And there are special types of tidal power turbine, and the rotation axis direction is perpendicular to the seawater flow direction, but the running direction of blade is not rotary, and the wing like hydroplane can move in the oncoming current by the lift or drag forces, such as Stingray tidal energy converter, which is shown in Fig. 9. At the same time, the sea surface have abundant solar energy and wind energy, so the tidal energy can combined with other renewable resource in order to improve the reliability of electricity [45–50].

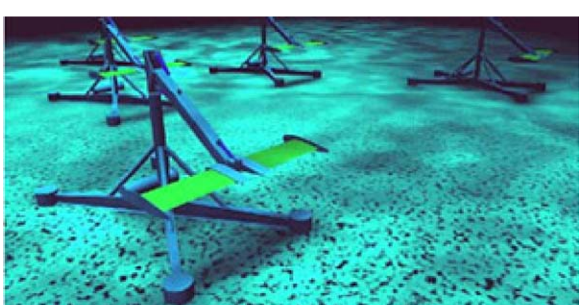


Fig. 9. Stingray tidal energy converter.
Ref. [50].

6. Tidal energy policies in China

The renewable energy has been regarded by the Chinese government in the last 10 years, and the Chinese Renewable Energy Law had been confirmed by the Chinese government in 28 February, 2005. According to the 12th conference of 11th Standing Committee of the National People's Congress, December 26, 2009, the revision decision of People's Republic of China renewable energy source law have been adopted. At present, the renewable resource have a rapid development velocity, such as the incredible growth rate of installed amount per year of wind power turbine is more than 100% in past 4 years, and the yield of photovoltaic is more than 4000 MW in 2009. But a harsh reality is that Chinese ocean energy has a little development over the past 20 years, and the total cumulative capacity and annual installed amount are very small. With the corresponding is that Chinese efficient development of tidal resource is more than 20 million kW. Certainly, in order to achieve sustainable development goal, the Chinese government and local governments formulates a series of policies and regulations to encourage tidal energy utilization. The correlative items contain: (I) The research investment of tidal energy must increasing in order to increase the proprietary intellectual property rights and core technology development ability. (II) The fund of tidal power plant is increasing due to private capital are unable to bear the high cost of tidal power plant. (III) The central government and local governments give some allowances to the tidal power plant. (IV) Local governments have formulated the tidal energy exploitation plan, such as Fujian and Zhejiang. (V) Some university and institute have developed the research of tidal energy. As mentioned above, the Chinese government regards the development and exploitation of tidal energy, and some hortative policies have been formulated, and the development prospect of tidal resources is enormous in future China [51].

7. Developmental barriers and prospect of tidal energy in China

At present, the development of Chinese tidal energy is ordinary compare with the rapid development of wind and solar energy exploitation. The main reason is that there are some policy barrier and financial barrier and price barrier and technology barrier, which obstructs the development of tidal energy exploitation in China.

(I) Policy barrier, the hortative policy of renewable resource has been established by the central government, but there are not specific and detailed implementation rules of tidal energy application, such as the development scale, development velocity, technical source and funding source. Furthermore, the dam and reservoir of conventional tidal power plant need flood large soil, which will impact the local ecological environment, and the construction must get government support. The construction and service of novel tidal stream power plant need occupy navigation channel, which need the require government approval. So the specific and detailed implementation rules must be formulated.

(II) Financial barrier, the development of tidal energy need abundant money due to the price of tidal power plant is costly, and the private capital cannot suffer the cost. Furthermore, the most abundant region of tidal energy located in remote islands and shores, and the financial capacity of local county government is limited, so the great investment of tidal power plant must get economic support of province government and central government.

Table 4
Development plan and prospect of renewable resource power in China.

Project	Installed capacity (10 MW)			
	Year			
	2010	2020	2030	2050
Small hydropower	5000	7500	10,000	20,000
Biomass power generation	550	2000	5000	10,000
Wind power generation	500	3000	10,000	40,000
Photovoltaic generation	30	180	1000	10,000

Refs. [52,53].

(III) Price barrier, the scale of tidal power plant in China is small, and the electric energy production is small, and the service area is small, and the grid electrovalence is about 0.1 dollar/kW h, which is more than the grid electrovalence of conventional power plant, such as the grid electrovalence of heat-engine plant in China is 0.03 dollar/kW h at present. So the ordinary people would rather use the conventional power due to the price. So the economic subsidy of government is must.

(IV) Technology barrier, the technology of tidal energy in China is not regarded by government and the experts and university and graduate school at present, and there are little university and institute concern the research field, certainly, the technical investment is not enough in that it is impossible to exploit the core technology. The interrelated technology of tidal energy is not gave a course in Chinese university, and no interrelated student graduate from the research field. The person with ability of tidal energy field is not cultivated in company and corporation.

At present, Chinese central government have planned ambitious object of renewable resource power, as shown in Table 4, and the total plan scale is very big. Specially, the actual development velocity of renewable resource exploitation is more than the plan velocity, such as the plan capacity of wind power generation in 2010 is about 5500 MW, but the actual accumulative installed capacity till 2009 is about 25,800 MW. Unfortunately, the development and use of tidal energy has not been given due attention. Local Government located in rich tidal energy areas of does not have the capacity to carry out large-scale development, so the tidal energy exploitation in China has a long way to go, which need the strongly support of central government, such as policy support, financial support and technology support. Certainly, with the rapid development of Chinese economy, and central government and local governments will more and more regard the renewable resource application, and the rich tidal resource areas located in the Chinese developed area, more and more power require need will compel local government to use the tidal energy, so the tidal energy exploitation in China will has a bright future [52,53].

8. Conclusion and recommendations

The distributing and development actuality and actual application and future prospect of tidal energy in China are described in this paper. Chinese economy development needs more and more energy in future with the rapid development of Chinese society, and increasing energy pressure forced the Chinese Government must find an alternative to traditional energy sources of renewable energy, so the renewable resource exploitation has been regarded by central government and local government at present, such as wind and solar energy. But a harsh reality is tidal energy development and utilization and did not get the attention it deserved. The tidal energy resource is abundant in China, and the total amount can be efficient development is more than 20 million kW, and distributing and rich area located in Chinese developed area, so the tidal energy power will be regarded by ordinary people and local governments and central government in foresee future.

Chinese sustainable development need improve the inopportune energy structure and regard the application of renewable resource. As noted above, the tidal energy exploitation does not be regarded at present, and some obvious barriers are existence, such as policy barrier, economy barrier, technology barrier, price barrier, so the development of tidal energy need the strongly financing support and policy support of central and local government in order to conquer the barriers. The following measures are especially recommended in this regard:

(I) The hortative policy of tidal energy exploitation should be refined by central government, such as developing tidal energy can get certain subsidies.
(II) The grid electrovalence of tidal power should be improved by power companies in order to encourage the development of tidal energy.
(III) The tax should be reduction/exemption by local government, which will motivate the enthusiasm of investor.
(IV) The interrelated research of tidal energy exploitation should be strongly support, and the universities and institute should be encouraged to research in tidal energy.
(V) Should vigorously promote the domestic and international cooperation in order to improve the research level in tidal energy.
(VI) The student should be trained by universities, and the interrelated course should be set up in order to provide qualified personnel of renewable resource exploitation region.
(VII) In order to possess core technology, the research investment should be improved.
(VIII) The merit of tidal power should be publicized by central and local media in order to increase the environmental awareness.

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